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DEVELOPMENT OF NEW HYDROMETRIC EQUIPMENT AND GAUGING STRUCTURES ON STABLE RIVERS

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DEVELOPMENT OF NEW HYDROMETRIC EQUIPMENT AND GAUGING STRUCTURES ON STABLE RIVERS

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INTRODUCTION

1. Hydrometry (the measurement of water, especially of the quantities, the levels, the velocities and the rates of flow or discharges) is an essential foundation for any measures aimed at the development, use or control of water resources. It is a distinctive feature of hydrometry that useful surveys are not only extensive in area but protracted in time.

2. The scientific bases of hydrometric methods and instruments are the same as those applied in many other sciences and technologies. The practical use of equipment similarly requires operators with skills which could equally usefully be employed in other fields. Those parts of the world in which hydrometry has become an established activity are, on the whole, populated by inhabitants accustomed to (or at least familiar with the idea of) measurement, to engineering control of the forces of nature, and to political and economic co-operation for the development of natural and other resources; living in countries most parts of which are easily accessible; and expecting perhaps a speedy, but hardly an "explosive" expansion of water development. The hydrometric instruments in common use today are relatively simple instruments requiring for a satisfactory survey large numbers of competent operators able to use them with both skill and judgement.

3. In less developed areas, the shortage of skilled man-power, the need for the most rapid possible advance on all frontiers of human activity, and frequently the difficulties of access and local support, all suggest that
   (a) the hydrometric survey be wide-spread in area and, with an early start, continuous in time;
   (b) the equipment used be capable of yielding all required answers with a minimum of investment of skill and judgement in installation, maintenance, servicing, checking, and reporting; and
   (c) both personnel and equipment be independent of local support and safe from unskilled or unsympathetic interference.

4. Requirements (a) and (b) above apply to all hydrometric surveys on which water development is to be based, wherever that may be, but there may be a difference in emphasis depending on the desired rate of development of water resources and the amount of information already available. Good hydrological analysis must be the foundation of good hydraulic design. If there are not enough records to permit a good hydrological analysis, and if hydraulic works are overdesigned or underdesigned, any subsequent collection and analysis of hydrometric data will indeed show up the error: but the cost of subsequent expansion of the works (if underdesigned), or the unnecessary excess in first cost (if the works were overdesigned), would probably greatly exceed the cost of speedily establishing and continuously operating a wide-spread hydrometric network.

5. The design of the best hydrometric networks requires a skilful team with a proper understanding of the personnel and the material resources available for surveys on the one hand, and of the technological and economic aspects of the desired water developments on the other. If for no other reason, new hydrometric equipment and methods have to be, and are being, developed because the desired size and timing of developments economically justifies larger surveys than the available personnel can undertake with older equipment.

PURPOSE OF MEASUREMENT AND AIM OF EQUIPMENT

6. In surface hydrology, the purpose of measurement is to obtain a knowledge, required for utilisation and control, of the quantity and variability of water quantity (level and discharge) and quality (other substances dissolved and solids suspended in the water); in particular, depending on the conditions in a locality or in a whole river basin, a knowledge of annual, seasonal, monthly, weekly or daily averages and of the magnitude, duration and frequency of maxima and minima. High water levels are of direct interest in flood control, and low levels in connection with the maintenance of navigation depths and of depths at artificial intakes. Indirectly and after calibration, levels are used as indicators both of discharge and of quality.

7. The aims of the equipment and of the method of its employment are: accuracy, completeness of coverage; ease and speed of operation; security of installation; economy in equipment and in skilled manpower; portability of instruments; and results permitting accurate, speedy and economical analysis.

DEVELOPMENT OF NEW HYDROMETRIC EQUIPMENT

8. Water level or "stage", is measured by means of staff gauges (vertical or inclined scales: rods, tapes), and where personnel is available this simple principle will continue to be used, especially for check readings for more complicated equipment. Special refinements are provided for the recording of maxima, and these involve the use of floating slides or of soluble dyes. Where a knowledge of the duration of a flood peak above certain levels is required and continuous recorders for such high levels are considered uneconomical, large calibrated containers with small orifice inlets at the specified levels may provide a cheaper solution. In order to allow levels to be measured more accurately, stilling wells are installed and provided with point or hook gauges or with floating staff gauges -- these are especially useful for precise check observations.

9. If continuous level records are required, floats in stilling wells are often employed to actuate indicators or recorders. Electrical (capacitative or resistance) devices are occasionally used in lieu of floats. The usual recorder is a chart device driven by a clock. In easily accessible places, weekly or even daily charts are used, but modern developments in battery-driven clocks now make it possible to operate strip charts for six months or more without attention.

10. Another type of level recorder operates in response to hydrostatic pressure changes brought about at a fixed level by the variations of the water surface. Until recently, the only reliable mechanism operating on this principle was a "bubbler" tube, fed from a compressed-gas bottle at a rate sufficient to ensure that in no flood, however sudden, would water be able to enter the tube. There must, therefore, be a steady, though slow, supply of gas into the tube. The pressure in the tube (which balances the water pressure at the tube outlet) is recorded on a barograph. The usual gas employed is air, either brought to the gauging site in high-pressure bottles or compressed, at intervals of a few

weeks, by means of a site pump; but some recent experimental "bubbler" apparatus is said to employ nitrogen or rare inert gases.

11. Another pneumatic water-level indicator, distinguished for its simplicity and cheapness, has now been improved to the point where its accuracy and durability seem to be assured. It is in essence a closed bellows anchored securely to the stream bed and also recording on a barograph. Whilst there should be no loss in gas, the sensitivity and accuracy of the indicator are lost if there is any kind of change in the elastic coefficient (or "aging") of the bellows.

12. The recording instruments are usually chart recorders, either with circular (rotating disc) charts on which the angle represents time and the radius the water level, or - more frequently - with cylindrical charts. If the timing drive rotates the cylinder, the range of paper over which water-level variations are recorded is limited by the height of the cylinder. This usually leads to a loss of accuracy in the recording of the lower and near-average levels which prevail for the greater part of the time, if provision is to be made for records of the highest possible levels. One way of overcoming this difficulty is to gear the drive for the level-recording pen logarithmically so that the scale progressively increases as the water level falls. Another method of increasing the scale consists of so designing the pen gear that the height of the cylinder represents the normal range of water-level variations and any unusually large rise causes the direction of the pen travel to be reversed.

13. The advantage of a chart which follows a cylinder rotating with time is that the chart may be a very long strip making the recorder largely independent for long periods (up to, say, one year: see paragraph 9). For most rivers, by far the greater part of such a long strip is apt to contain a trace with little variation, but with some short sharp peaks (representing floods). In the interest of economy of paper and evaluating effort and, especially, in the interest of accuracy, it appears desirable to design a timing drive with two speeds - slow for low levels with slow variations and rapid for the higher levels with pronounced change. The use of such two-speed recorder charts may also demand a revision of the equipment used in evaluating results (e.g. special planimeters). A useful speed ratio might be as high as 20:1.

14. The cylindrical recorder with an axial time drive permits rotation beyond 360° and so, in theory, gives unlimited freedom of choice of water-level scales for a given size of chart. Its disadvantage lies in the necessity to change the chart (or, at least, to reset the pen) when the time corresponding to the length of the cylinder has elapsed. For use in inaccessible places, a recorder with a device permitting automatic resetting of the pen at the end of the design period would perhaps be of advantage.

15. Until recent years, the only type of recorder used in hydrometry was the "analogue" in which a pen or stilus traces a line on a paper chart or a metal sheet. In the past decade "digital" devices have been developed which usually leave a record in the form of a punched tape. In principle, the gearing of digital recorders is as simple as that of the analogue ones, but various refinements common in other modern industrial applications of recorders tend to be incorporated in them so that their cost is still relatively high. Punched tape has the great advantage of permitting immediate high-speed analysis by modern computers, including a type of "auditing" or verification of the validity of the records.

16. The subject of recorders is of great importance in hydrometry, for the greater part of the best surface-water data is derived from these instruments. The older type, installed in accessible places and serviced by skilful technicians, gives reliable and fairly economical results. For the large hydrometric programmes likely to be needed in less developed countries, however, and for special purposes such as flood forecasting, the older type is wasteful of skill and time, and the potentialities of the new developments deserve to be studied in full. The main advantages of digital devices in this respect derive from the fact that they generate and transmit their information in the form of finite steps or increments or pulses which are comparatively insensitive to disturbances and, incidentally, readily lend themselves to magnification. Both for inaccessible stations, therefore, and for those from which information is required very speedily (for forecasting), the newest radio or telephone-reporting apparatus seems e[illegible]: so far the equipment under test is still costly aswell as apt to give occasional trouble, but the operating principle of transmitting information on water levels at regular intervals, or on request, usually in digital form, is so simple that speedy improvements in design and construction may be confidently anticipated. The conclusion to be drawn from this is that a small but skilful team, perhaps made highly mobile by a helicopter, will soon be capable of installing and servicing a basic network of radio-reporting recorders, with a secondary network of local tape recorders, covering a river basin extending to t[illegible] of thousands of square miles.

17. The indirect use of water levels as indicators of discharge is very common. This requires a calibration process usually yielding a stage-discharge curve or a family of such curves. The most common method of calibration is by means of the velocity-area method and more particularly by the use of current meters placed successively at points of measured distance from the river bank and depth below water surface. The cup type of meter is comparatively cheap, robust and insensitive to silt and seems to be approaching the limit of its possible development. It reads the maximum velocity in the plane perpendicular to its axis, with a slight speeding up if there is an axial flow component, and therefore tends to over-record discharge. The screw type ("propeller") has a speed response to the flow velocity which may be arbitrarily chosen in terms of the pitch; its size brings the ideal of measurement of point velocities nearer; and modern developments of blade shapes ("cosine-reading") permit the axial velocity component to be recorded, which is desirable if the instrument axis can be held parallel to the river axis or if the meter could be provided with an instrument indicating exactly the position and direction of the axis. To give a good velocity reading at any point, the current meter must be held there for at least two runs of at least 30 seconds each. Cosine-reading meters permit a considerable speeding up of the process: a traverse of the cross-section of the river in a series of verticals or in a zig-zag pattern provides its own integration to yield the direct result of the total discharge.

18. In a large river, the difficulty of accurately determining the size of the channel cross-section and the position of the current meter (especially if suspended from a boat) is great. Speed and accuracy of observation may be improved by the replacement of horizontal tapes and of sextant or theodolite controls by Radar or Sonar measurement, and by the replacement of sounding rods and cables by echo-sounders.

19. Alternatives to current meters for the measurement of local velocities are the speedy and sensitive pressure (Pitot or membrane) or hot-film devices, which may repay further industrial development. Freedom from silt clogging of propeller meters may be brought about by improvements in the design of rotor bearings and by magnetic or capacitative couplings of the rotor to a completely sealed recorder.

20. A direct measurement of the mean velocity may be obtained by timing the passage through a measured length of river of a suddenly injected chemical or radio-active indicator ("salt-velocity" method). Present developments aim at ensuring that the indicator is representatively spread across the whole section of the river and that the material chosen is not affected by the bed material.

21. If chemical or radio-active tracers are permissible and suitable, the direct measurement of discharge by the "salt-dilution" method is usually preferable to the velocity method. Here a tracer is injected into a river at a known constant rate and concentration and, when completely and uniformly mixed with the natural discharge, indicates the magnitude of that discharge by the reduction in its concentration. Experiments continue to provide us with chemicals of the required degree of inertness and capable of being accurately measured in minute concentrations: it may be expected that this form of hydrometry will become much more prominent in future.

22. A major difficulty in establishing the stage-discharge curve for a river section by any velocity-area method or by salt dilution lies in the need for repeated observation to establish numerous points on the curve, with little chance of being present during the infrequent extremes. Even if the team is present during a flood, the dangers and practical difficulties of observation are very great.

PRINCIPLES OF "CONTROL"

23. In open-channel hydraulics, the term "control" denotes an artificial weir, notch, flume, or culvert, or a natural rock bar or other obstacle, which permits the instantaneous discharge to be uniquely related to one or two water levels. "Free" flow occurs if the Froude Number at the control section exceeds unity. With a free flow over the whole range of discharges, a single water-level recorder installed at (or a short distance upstream of) the control provides continuous information on discharge. In nature it often happens that over part of the range the flow is "submerged", but it is usually found that continuous records of water levels at the control and at a suitable section upstream, while requiring double the instrumentation, will still economically provide accurate information on discharges.

24. Where a control occurs at considerable distances from river junctions, a single water-level record suffices to indicate "submerged" discharges, but the method of establishing a stage-discharge curve in that case is likely to be a velocity-area or salt-dilution programme: the advantages of "pure control", as obtained in weirs etc., are lost.

25. If "pure control" is available, the degree of accuracy of discharge computation may be as high as desired and -- a most important advantage in a "crash" programme -- the whole of the stage-discharge curve may be accurately established without waiting for extreme discharges to occur in nature.

26. Entirely artificial structures, even more than modified natural controls, have the great merit of giving the designer considerable latitude in determining the accuracy of discharge computation corresponding to a given accuracy of level measurement at various stages. Artificial gauging structures may be built to standard dimensions for which the stage-discharge curve has already been determined. Non-standard structures and natural control sections have to be calibrated, and the best calibration is by means of scale models.

27. On the basis of mechanical similarity, models of control structures (in which gravity forces predominate over viscous and surface-tension forces) are built to a reduced scale without distortion. The predominant similarity criterion is the Froude Number, and the discharge ratio is accordingly very nearly $r^{2.5}$ (where r denotes the linear scale ratio). To allow for "scale effects", e.g. the minor effects of the lack of similarity of the viscous forces, corrections are applied which are based either on experience with past model calibrations for similar structures or on studies on several models of the given structure built to various scale ratios.

GAUGING STRUCTURES ON STABLE RIVERS.

28. The hydraulic design of weirs, notches and flumes is a well-documented branch of hydraulic engineering. On very large rivers, the provision of artificial structures solely for gauging pruposes is likely to be too costly and protracted an undertaking to be of practical interest. It should, however, be borne in mind that the construction of any dam, barrage, bridge, embankment with culverts etc. provides control sections of known dimensions: single or twin water-level recorders will yield a good basis for hydrological work.

29. Stable rivers are those where the variation with time of the cross-section is negligible. In practice this occurs where rivers flow over a rocky bed, and is not so rare as has been suggested. Even where rivers move through vast alluvial plains, artificial stabilisation of the bed and banks, especially at structures built for water-control purposes or at bridges, may be a practical proposition.

30. On many rivers on which a major gauging programme will become necessary in the near future, preliminary surveys will reveal cataracts, gorges or sharp rocky bends, as well as the rock bars forming the classical equivalent to a gauging weir. As the quality of a hydrological design for the control and use of water is a function of the duration of record, in most cases, it is of great importance to establish water-level recorders at one or more of such natural controls at the earliest possible moment. Checks of the stability of cross-section may be made two or three times a year - perhaps before and after a flood season - but the second main purpose of such checks will be to build up a survey of the shape of the river in the vicinity of the control. The construction and calibration of one or more scale models may wait until a detailed study of the water resources is ripe: with a long water-level record and a stage-discharge curve deduced from a good model calibration, a very accurate picture of the averages and of the variability of the surface water resources in a basin may be obtained at a remarkably small cost and with a very brief employment of highly skilled personnel.

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